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Neural network for bending moment in continuous composite beams considering cracking and time effects in concrete

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Abstract

A methodology using a neural network model has been developed for the continuous composite beams to predict the inelastic moments (typically for 20 years, considering instantaneous cracking, and time effects, i.e. creep and shrinkage, in concrete) from the elastic moments (neglecting instantaneous cracking and time effects). It is shown that the redistribution of elastic moment at a support due to instantaneous cracking along with time effects depends primarily on the instantaneous cracking at the support and adjacent supports and also that the redistribution is independent of absolute span lengths. The proposed neural network model predicts the inelastic moment ratio (ratio of elastic moment to inelastic moment) using eight input parameters. The training and testing data for the neural network is generated using a hybrid analytical–numerical method of analysis. The models have been validated for four example beams and the errors are shown to be small. The methodology enables rapid estimation of inelastic moments and requires a computational effort that is a fraction of that required for the time dependent analysis. The methodology can be extended for the composite building frames resulting in huge savings in computational time.

Keywords: Neural network; Creep; Shrinkage; Composite beam; Concrete cracking

1. Introduction

Redistribution of elastic moments in continuous composite beams (Fig. 1(a)) occurs due to instantaneous cracking in concrete in hogging moment regions, as well as time effects (creep and shrinkage) in concrete. Methods are available in the literature for analysis of the beams, which take into account this moment redistribution. These methods are based either on an incremental or iterative approach. Both the approaches require a computational effort, which is many times more than that required for the elastic analysis (neglecting instantaneous cracking and time effects). The use of neural networks may be made to drastically reduce the computational effort.

Principles and applications of neural networks in civil engineering have been summarized in the works by Flood and Kartam [1,2] and Adeli [3]. Neural network based models have been recently applied in the field of structural engineering for the structural analysis of masonry infilled steel frames [4], prediction of shear strength of RC beams [5], prediction of ultimate shear strength of deep beams [6], structural reanalysis using iterative method [7], generation of artificial earthquake and response spectra [8], diagnosis of structural damage [9], damage assessment of cable stayed bridges [10], damage detection of bridges [11,12], evaluation of ultimate strength of steel panels [13], evaluation of existing bridges [14], optimum design of cold-formed space structures [15], prediction of time effects in reinforced concrete frames [16], establishing size effect on shear strength of beams without shear stirrups [17], shear strength design of beams without stirrups and with stirrups [18,19] and estimation of concrete strength [20–22]. These studies reveal the strength of neural networks in predicting the solutions of different structural engineering problems.

In this paper, a methodology using a neural network has been developed to estimate the inelastic moments in continuous composite beams, M^i (considering the instantaneous cracking and time effects in concrete) from the elastic moments, M^e

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Nomenclature

E	modulus of elasticity of concrete
I^{cr}	transformed moment of inertia of steel section and reinforcement about top fibre
I^{un}	transformed moment of inertia of composite section about top fibre
M^e	elastic moment
M^i	inelastic moment
M^{cr}	cracking moment
S	stiffness
l	span length
n	number of spans
w	uniformly distributed load
w^{cr}	cracking load
η	percentage variation in elastic moment

subscript

j, k, n	support or span number

(neglecting the instantaneous cracking and time effects in concrete). M^e can be obtained from any of the readily available software. The methodology enables rapid estimation of M^i and requires a computational effort that is a fraction of that required for the methods available in the literature.

The neural network models predict the M^i (typically at 20 years) due to instantaneous cracking and time effects. The neural network models have been validated for four example beams. The errors are shown to be small for practical purposes. The methodology can easily be extended for large composite building frames where a very significant saving in computational effort would result.

2. Analysis of continuous composite beams

For generalized and efficient neural networks, a huge number of training data sets are required for which a highly efficient method is desirable. Recently, a hybrid analytical–numerical procedure has been developed [23] to take into account the nonlinear effects of concrete cracking and time-dependent effects of creep and shrinkage in composite beams and frames. The procedure is analytical at the element level and numerical at the structural level. A cracked span length beam element consisting of uncracked zone in the middle and cracked zones at the ends (Fig. 1(b)) has been used in the procedure.

The analysis in the hybrid procedure is carried out in two parts. In the first part, instantaneous analysis is carried out using an iterative method. In the second part, time-dependent analysis is carried out by dividing the time into a number of time intervals to take into account the progressive nature of cracking of concrete. In time analysis crack length is assumed to be constant and equal to that at the beginning, as shown in Fig. 1(c).

The Age-Adjusted Effective Modulus method is used to account for the variation of the modulus of elasticity with

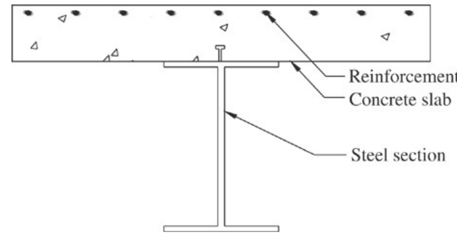

Fig. 1(a). Composite cross-section.

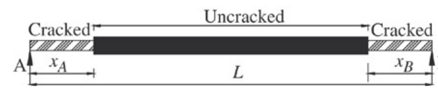

Fig. 1(b). Cracked span length beam element.

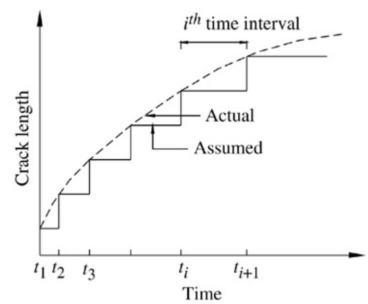

Fig. 1(c). Progressive nature of cracking.

the age of loading and creep [25]. Further, in the procedure the variation of tensile strength with time has been taken into account in accordance with the provisions of the CEB-FIP model code 1990 [26].

The procedure has been validated by comparison with the experimental results, analytical results, and FEM model using ABAQUS. This procedure is adopted in the present work.

3. Significant extent of propagation of the effect of cracking

Cracking in continuous composite beams occurs in the end portions (where hogging moment occurs) of spans at intermediate supports when subjected to loading that causes instantaneous cracking in end portions. This instantaneous cracking may further progress due to time effects. The elastic bending moments M^e at an instantaneous state gets redistributed to M^i at an instantaneous state owing to cracking and at a final state (typically 20 years) gets further redistributed owing to time effects that may also result in further concrete cracking.

The redistribution of the moments along the length of a beam due to instantaneous cracking at a support reduces along the distance from the support. A preliminary numerical study is carried out to estimate the significant extent of propagation of the effect of instantaneous cracking, at a support at instantaneous and final stages. For the study, a typical multi-span (number of spans $= n$) continuous composite beam, shown in Fig. 2(a), is considered. The cross-sectional properties throughout the beam are kept constant unless otherwise stated. The nature of the elastic moment diagram for the beam with